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EXOTIC NARROW RESONANCE SEARCHES IN THE SYSTEMS ΛK_S^0

P. Zh. Aslanyan [a,b,1], *V. N. Emelyanenko* [a], *G. G. Rikhvitzkaya* [a]

[a] Joint Institute of Nuclear Research, Dubna
[b] Yerevan State University, Yerevan, Armenia

A number of peculiarities were found in the effective mass spectrum of system ΛK_S^0 in the ranges 1650–1680, 1740–1750, 1785–1805, 1835–1860 and 1925–1950 MeV/c^2 in collision of a 10-GeV/c^2 momentum proton with propane. The detailed research of the structure of mass spectrum has shown that the significant enhancements have been obtained in two effective mass ranges of 1750 and 1795 MeV/c^2. These peaks could be interpreted as possible candidates of two pentaquark states: the N^0 with quark content $udsds$ decaying into ΛK_S^0 and the Ξ^0 resonance with quark content $udssd$ decaying into $\overline{\Lambda K_S^0}$.

В спектре эффективных масс системы ΛK_S^0 обнаружен ряд особенностей при значениях 1670–1680, 1740–1750, 1785–1805, 1835–1860 и 1925–1950 МэВ/c^2. Детальное исследование структуры вышеуказанного спектра показало, что максимальные сатистические значимости получаются при значениях эффективных масс 1750 (5,6 S. D.) и 1795 (3,3 S. D.) МэВ/c^2. Эти пики интерпретированы как отражения от двух состояний: N^0 с кварковым составом $udsds$ по каналу распада в ΛK_S^0 и Ξ^0-резонанс с кварковым составом $udssd$ по каналу распада в $\overline{\Lambda K_S^0}$.

INTRODUCTION

Several models predict the multiplet structure and characteristics of pentaquarks, for example, the chiral soliton model, the uncorrelated quark model, correlated quark models, QCD sum rules, thermal models, lattice QCD, etc. [1–18]. Multiquark states, glueballs and hybrids have been experimentally searched a long time ago, but none is established.

Results from a wide range of recent experiments in [19] (P. Zh. Aslanyan et al.) are consistent with the predicted $S = +1$ exotic Θ^+ resonance [1], which were $\Gamma_{\Theta^+} = (9.2 \pm 1.8)$ MeV/c^2 and $M_{\Theta^+} = (1540 \pm 8)$ MeV/c^2. These M_{Θ^+} and Γ_{Θ^+} are consistent with such ones from PDG-2004 [32].

However, the significant advances in theoretical and experimental work achieved over the last two years of searches led to finding a number of new pentaquarks candidates: $\Xi^{--}(1862)$, $\Xi^-(1850)$, $\Xi^0(1864)$ [20] and the $\Theta_c^0(3099)$ [21]. Preliminary results of the STAR (Solenoidal Tracker At RHIC) on a search for the Ξ^0 $I = 1/2$ as well as for the N^0 or the Ξ^0 pentaquark states in the decay mode ΛK_S^0 with the mass $(1734 \pm 0.5 \pm 5)$ MeV/c^2 were presented in [22]. A significant signal for $\approx \Xi^0(1750) \to \Xi^-\pi^+$ was observed in [23].

[1] E-mail: paslanian@jinr.ru

1. EXPERIMENT

The experimental information of more than 700000 stereo photographs from the JINR LHE 2-m bubble chamber [24–26] was used to select the events with V^0 strange particles.

The V^0 events with Λ hyperon and K^0_S meson were identified by using the following criteria [25, 26]:

1) V^0 stars from the photographs were selected according to $\Lambda \to \pi^- + p$, $K^0_S \to \pi^- + \pi^+$ and $\gamma \to e^+ + e^-$ hypothesis. Low momentum limits of K^0_S and Λ are greater than 0.1 and 0.2 GeV/c, respectively; 2) V^0 stars should have the effective mass of K^0_S or of Λ; 3) the V^0 momentum and momenta of particles from the V^0 decay must be located in the same plane (coplanarity); 4) three-constraint fit for the M_K or M_Λ hypothesis was used and after $\chi^2_{V^0}$ should be selected over a range less than 12; 5) it was shown that the events with undivided ΛK^0_S were assumed to be Λ hyperons [25].

The invariant mass distributions of 8657 events of Λ hyperons, 4122 events of K^0_S mesons were consistent with their mass values from PDG [32] (Fig. 1). The effective mass resolution of ΛK^0_S system was estimated to be on the average 1 %.

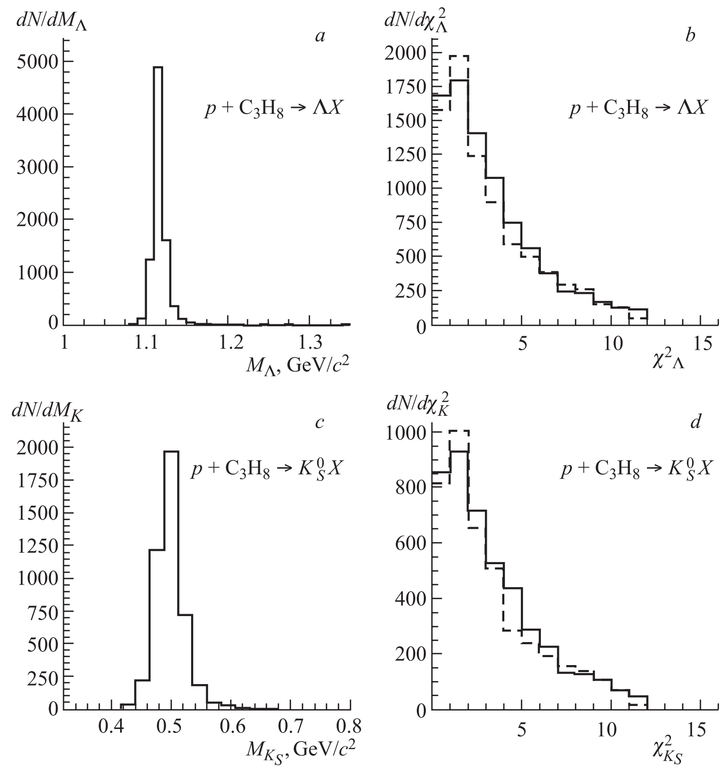

Fig. 1. The distribution of experimental V^0 events produced from interactions of beam protons with propane: *a*) for the effective mass of M_Λ; *b*) for $\chi^2_\Lambda(1V - 3C)$ of the fits via the decay mode $\Lambda \to \pi^- + p$; *c*) for the effective mass of $M_{K^0_S}$; *d*) for $\chi^2_{K^0_S}(1V - 3C)$ of the fits via decay mode $K^0_S \to \pi^- + \pi^+$. The expected functional form for χ^2 is depicted by the dotted histogram

Each V^0 event weighted by a factor $w_{\rm geom}$ $(= 1/e_\tau)$, where e_τ is the probability for potentially observing the V^0, it can be expressed as

$$e_\tau = \exp\left(-L_{\rm min}/L\right) - \exp\left(-L_{\rm max}/L\right),$$

where $L(= cp\tau/M)$ is the flight length of the V^0; $L_{\rm max}$ is a path length from the reaction point to the boundary of fiducial volume, and $L_{\rm min}$(0.5 cm) an observable minimum distance between the reaction point and the V^0 vertex. M, τ, and p are the mass, lifetime, and momentum of the Λ hyperons and K^0_S mesons. The average geometrical weights were 1.34 ± 0.03 for Λ and 1.22 ± 0.04 for K^0.

Experimental data analysis was made using FRITIOF model [28, 29], as one background method, for collision $p + \text{propane} \to \Lambda(K^0_S)X$. The experimental data are described by the FRITIOF model satisfactorily [26].

2. ΛK^0_S-SPECTRUM ANALYSIS

The total experimental background has been obtained by three methods (Fig. 2). In the first method, the experimental distribution on effective mass with removed areas of the resonance was approximated by the polynomial function while this procedure has provided the fit with $\chi^2 = 1$ and polynomial coefficient with errors less than 30%. The second method, where the

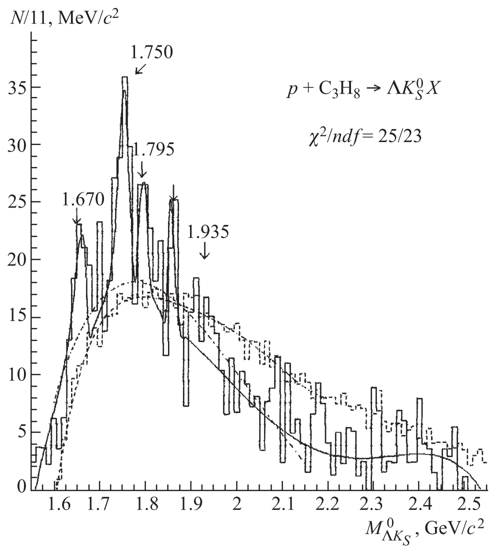

Fig. 2. Invariant mass distribution (ΛK^0_S) in the inclusive reaction $p + C_3H_8$. The solid curve is the sum of the experimental background by the first method (the dotted-dashed curve) and three Breit–Wigner resonance curves. The dashed histogram is the simulated background by FRITIOF model [28]

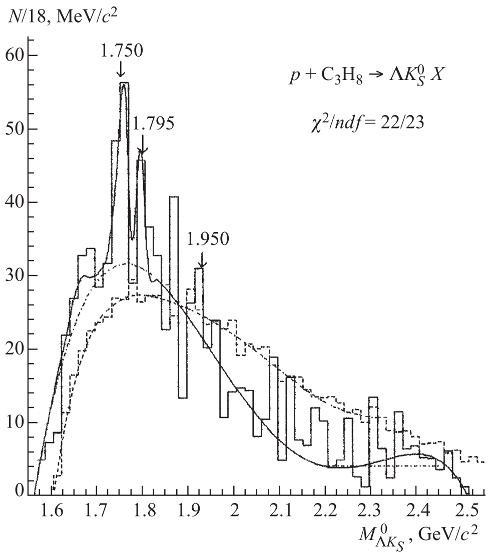

Fig. 3. Invariant mass distribution (ΛK^0_S) in the inclusive reaction $p + C_3H_8$. The solid curve is the sum of the experimental background by the first method (the dotted-dashed curve) and two Breit–Wigner resonance curves. The dashed histogram is the simulated background by FRITIOF model [28]

angle between K_S^0 and Λ for experimental events is randomly mixed, was described in [27]. This background was obtained by using our experimental condition. Then, the effective mass distribution (ΛK_S^0) was fitted by the polynomial function. The third type of background for (ΛK_S^0) combinations has been obtained by FRITIOF model [28] (Fig. 2). In all the figures the simulated background distribution has been normalized to the experimental distribution. The statistical significance of resonance peaks were calculated as $\mathrm{NP}/\sqrt{\mathrm{NB}}$, where NB is the number of counts in the background under the peak and NP is the number of counts in the peak above background.

Figure 2 shows the invariant mass of 1012 (ΛK_S^0) combinations with bin sizes 11 MeV/c^2. The solid curve is the sum of the background defined by the first method and four Breit–Wigner resonance curves (Fig. 2). The values for the mean position of the peak and the width were obtained by using Breit–Wigner fits. There are statistical enhancements in mass regions of 1670, 1750, 1795 and 1850 MeV/c^2 (Fig. 2). The excesses above background are 2.9, 4.7, 2.3 and 2.4 S.D., respectively. The simulation with FRITIOF model for (ΛK_S^0) combinations is shown in Fig. 2. As seen from Fig. 2, there is no significant reflection from well-known resonances in this distribution.

The effective mass distribution of (ΛK_S^0) with bin size 18 MeV/c^2 is shown in Fig. 3. This bin size is consistent with the experimental resolution within the errors. The solid curve is the sum of the background by the first method and two Breit–Wigner resonance curves (Fig. 3). There are significant enhancements in mass regions of 1750 and 1795 MeV/c^2. Their excess above background by the first method is 5.6 and 3.3 S.D., respectively. There are negligible enhancements in mass regions of 1680 and 1935 MeV/c^2. Similar results have been obtained for the peak in the mass region 1740–1750 MeV/c^2 when different bin sizes such as 10, 11, 18 and 21 MeV/c^2 were used.

CONCLUSIONS

A number of peculiarities were found in the effective mass spectrum of system ΛK_S^0 in ranges of 1650–1680, 1740–1750, 1785–1805, 1835–1860 and 1925–1950 MeV/c^2 in collisions of protons of 10-GeV/c momentum with propane. The detailed research of the structure of mass spectrum has shown that the significant statistical enhancements have been obtained in two effective mass ranges shown in table.

The effective mass, the width (Γ) and the statistical significance of resonances produced in collisions of protons with propane at 10 GeV/*c*

Resonance decay mode	$M_{\Lambda K_S^0}$, MeV/c^2	Experimental width Γ_e, MeV/c^2	Γ	The maximal statistical significance N_{sd}
$K_S^0\Lambda$	1750	32	14 ± 6	5.6
$K_S^0\Lambda$	1795	44	26 ± 15	3.3

The preliminary total cross section for $N^0(1750)$ production in $p +$ propane interactions is estimated to be $\approx 30\,\mu$b.

The N^0 can be taken as a member of antidecuplet, or of an octet (D. Diakonov, V. Petrov [1], V. Guzey and M. Polyakov [2]) or of a 27-plet (J. Ellis et al., [8]). On the other hand, Jafe and Wilczek predicted a mass around 1750 MeV and a width 50% larger for these states than that of the Θ^+ [5].

These peaks could be interpreted as possible candidates for two pentaquark states: the N^0 with quark content $udsds$ decaying into ΛK_S^0 and the Ξ^0 resonance with quark content $udssd$ decaying into $\Lambda\overline{K_S^0}$, which agree with the calculated rotational spectra N^0 and Ξ^0 spectra from the theoretical reports of D. Akers, V. H. MacGregor [30], A. A. Arkhipov [31].

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